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Rate of decomposition of cellulose in forest soils in various parts of the Nordic countries

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Abstract

Lähde, Erkki. (For. Res. Inst., 96300 Rovaniemi 30, Finland). Rate of decomposition of cellulose in forest soils in various parts of the Nordic countries. Rep Kevo Subarctic Res Stat 11. 72—78. — 1974. The rate of decomposition of cellulose in the soil decreases from south to north within the Nordic countries. The greatest decrease occurs between southern and northernmost Finland. In a pine stand in Utsjoki the rate of decomposition is at the most 1/6 of what it is in a corresponding pine stand in southern Finland. In a birch stand in Utsjoki the decomposition is 2—3 times faster than in a pine stand in the same area. During different seasons the decomposition is most rapid in the spring and early summer, but even in the winter considerable decomposition occurs. The differences in rate of decomposition in different environments must be considered when evaluating littering of forests and using containers of different firmness in reforestation with containerized seedlings.

1. Introduction

The rate of decomposition of forest litter has long been used as an indication of soil fertility and decomposition activity. In order to avoid the disappearance of material and to improve the reliability of the results in field experiments, the litter has been enclosed in glass fiber (Mikola 1954; 1960) or nylon mesh (Bocock & Gilbert 1957; Shanks & Olson 1961, or it has been submerged in the soil in a bag made of metal mesh (Nömmik 1930) or perlon mesh (Zaguralskaya 1967). Instead of using litter as the material to be decomposed, other solid material also may be used. The composition of such material corresponds partly or totally to that of the litter. E.g. cellulose of various forms is a useful material. Often-used methods are those where the rate of decomposition has been measured for viscose silk thread (measured as decrease of tensile strength) (Richard 1945), cellulose cotton (Unger 1960), cellophane (Berger—Landefeldt 1960), and pure cellulose (Colley 1960; Paarlahti 1964; Lähde 1966; 1969). Using the same basic methods the microbes decomposing organic material of the soil may be studied (Tribe 1957; 1960 a; 1960 b; 1961; Ruschmeyer & Schmidt 1958; Schmidt & Ruschmeyer 1958).

The rate of decomposition of cellulose also reflects the speed of decomposition of other organic material adjacent to the cellulose since the faster the litter is decomposed the more it increased the rate of decomposition of cellulose (Nömmik 1938; Bornebusch 1946; Beijerinck & Pelkwijk 1950). The rate of decomposition of litter and other corresponding material in the soil depends on ecological and biological conditions. Of the physical properties of the soil, temperature, moisture and oxygen supply are especially important factors. Most kinds of litter are decomposed faster at high, as compared to low, temperatures (e.g. Mork

1938; MIKOLA 1954; DAUBENMIRE & PRUSSO 1963). Of the chemical properties of the soil, the pH and the amounts of nutrients especially, and above all the nitrogen content affect the rate of decomposition of litter and pure cellulose (BAUMANN & DENK 1950; ISOTALO 1951; TRIBE 1961; LÄHDE 1969).

The timber crop, the growth and quality of which is dependent on the same soil properties, also affects the soil through its litter. For instance, at the same site the rate of decomposition of cellulose is much faster in a hardwood than in a softwood stand (LÄHDE 1966). In a dense spruce stand the snow and ground frost thaw faster than in a thinned stand (YLI-VAKKURI 1960). LÄHDE (1966) found that this affected the rate of decomposition so that in a *Vaccinium*-type pine stand it was faster than in a spruce stand at the same site type. Birch as a mixture species increases the rate of decomposition in a softwood stand.

The geographical location and the macroclimatic conditions are also reflected in the rate of decomposition of organic material. In Finland e.g., the decomposition rate of litter decreases considerably from south to north (MIKOLA 1960).

In the present study an attempt was made, using the cellulose method, to determine to what extent the geographical location and, on the other hand, differences in the kind of timber crop affect the decomposition activity in various parts of the Nordic countries.

2. Methods

The experimental plots chosen for study are the same as those on which several other ecological and biological studies have been done within the International Biological Program (IBP). The southernmost experimental plots are located in Denmark and southern Sweden, while the northernmost is in the very north of Finland at Kevo, Utsjoki (Table 1). More detailed descriptions of the stands will be given in the publication by the main scientists within the IB program. One part is already published (e.g. ANDERSSON 1970 a; 1970 b; KÄRENLAMPI 1972).

The decomposition activity of the soil was measured by using the cellulose-decomposition method. Pieces of cellulose (size 1.5x3.0 cm) of known dry weight were submerged in the soil. The material was bleached, 1.5 mm thick sulphite cellulose carboard containing about 95 % α-cellulose. Pieces cut out of the carboard were fastened with staples into nylon mesh bags (4 pieces/bag), and the bag was submerged in the soil in a slanting position so that the edge of the uppermost piece was at the soil surface, and the lowest was at a depth of 4.5—6.0 cm. The 40 bags per experimental plot were submerged on September 5—15, 1969. Half of them were lifted in the beginning of the next June (June 5—15, 1970), and the rest after a year from the beginning of the experiment. The method used has been described in earlier reports (PAARLAHTI 1964; LÄHDE 1966; 1969).

3. Results and Discussion

3.1. Rate of decomposition from fall to spring

The differences in the decomposition of cellulose from fall to spring on the various experimental plots are statistically significant (Table 2). In the pine stand of Juupajoki (southern Finland) the decomposition is clearly most rapid in all soil layers. In the beech stand of Aarhus (Denmark) the decomposition in the top layer (0—1.5 cm) is as rapid as in the oak-hazel mixed stand of Lund (southern Sweden), but in the deeper layers (1.5—6.0 cm) it is faster. In the spruce stand of Juupajoki and the spruce-birch mixed stand of Kuusamo (Oulanka) the decomposition is much slower compared to the above-mentioned experimental plots. Close to the soil surface (0—3.0 cm) the decomposition is somewhat faster than in Kuusamo, but the differences between the rate of decomposition in the deeper layers is not statistically significant. The results from the northernmost experimental plots in Utsjoki, Kevo are rather

Table 1. Location of the experimental plots, and main species of the stand.

Location	Coordinates	Main species
Aarhus, Denmark	56°15'N; 10°10'E	Beech
Lund, Sweden	55°45'N; 13°20'E	Oak-hazel
Juupajoki, Finland	61°50'N; 24°20'E	Pine
Juupajoki, Finland	61°50'N; 24°20'E	Spruce
Kuusamo, Finland	66°20'N; 29°15'E	Spruce-birch
Utsjoki, Finland	69°45'N; 27°00'E	Birch
Utsjoki, Finland	69°45'N; 27°00'E	Pine

Table 2. Weight loss (percent of dry weight) from fall to spring (1969-09-10. . .1970-06-10) of cellulose on the experimental plots at various depths of the soil.

Depth cm	Location and stand							F	HSD 5 %
	Aarhus Beech	Lund Oak-hazel	Juupajoki Pine	Juupajoki Spruce	Kuusamo Spruce-birch	Utsjoki Birch	Utsjoki Pine		
0—1.5	72.1 ± 24.2	72.4 ± 16.9	89.0 ± 12.6	43.8 ± 18.4	31.7 ± 14.3	14.5 ± 6.1	3.1 ± 3.0	4.37***	32.0
1.5—3.0	67.2 ± 29.9	59.9 ± 14.6	89.8 ± 11.0	42.9 ± 14.6	32.7 ± 12.1	12.0 ± 5.4	2.2 ± 3.8	3.50**	33.0
3.0—4.5	65.4 ± 21.9	48.0 ± 14.6	87.5 ± 12.2	37.5 ± 15.9	36.0 ± 16.6	9.7 ± 6.0	0.4 ± 0.6	3.71**	33.0
4.5—6.0	57.3 ± 22.6	41.3 ± 15.4	76.9 ± 13.1	30.8 ± 15.0	35.9 ± 15.5			1.33	33.0
F	1.23	15.84***	4.81**	2.80*	0.45	3.31*	4.88*		
HSD 5 %	24.9	12.8	10.2	13.3	12.2	3.6	2.1		

different from those located in the south. In the birch stand of Utsjoki the rate of decomposition is not even 50 % of that on the plot in Kuusamo, and in the pine stand the decomposition is only 20 % compared to the birch stand in the same location. The difference in rate of decomposition between the pine stands of Utsjoki and Juupajoki is quite large. In the surface layer at Utsjoki the rate is only 1/10 of that at Juupajoki and is still less in the deeper layers.

Vertically, the speed of decomposition is reduced toward the deeper soil layers except at the plot at Kuusamo where significant differences between layers were not observed. The differences between the layers were more pronounced on the other southern and more northern experimental plots.

The differences in ecological and biological factors due to geographical location, soil quality of the site, and the timber crop are clearly reflected in the rate of decomposition from fall to spring. In the open pine stand in Juupajoki, where the snow melts early, the soil temperature rises quickly since the soil is permeable. The rate of decomposition is faster than on the more southern experimental plots and even twice as fast as in the more fertile spruce stand on the same location. The differences in rate of decomposition during winter and spring between a pine, spruce and larch stand within the same location is probably due primarily to differences in the time of melting of the snow and thawing of ground frost in those stands. According to LÄHDE (1966) the rate of decomposition of cellulose from November 1964 to May 1965 in the Helsinki area was twice as fast in a *Vaccinium* site type pine stand compared to an *Oxalis-Myrtillus* site type birch stand and manifold compared to a *Vaccinium* site type spruce stand.

In Denmark (Aarhus) the decomposition rate is faster below the surface layer compared to the same layers at the experimental plot in Sweden (Lund). At the experimental plot of Juupajoki the rate is much slower than at the two abovementioned plots. In the surface soil of the thick-humus spruce plot in Kuusamo the rate was slower than in Juupajoki, but already below 3 cm it was faster. In Lapland the snow often falls before any long periods of cold, resulting in a non-

Table 3. Weight loss (percent of dry weight) during one year (1969-09-10...1970-09-10) of cellulose on the experimental plots at various depths of the soil.

Depth cm	Location and stand							F	HSD 5 %
	Aarhus Beech	Lund Oak-hazel	Juupajoki Pine	Juupajoki Spruce	Kuusamo Spruce-birch	Utsjoki Birch	Utsjoki Pine		
0—1.5	96.5 ± 9.8	96.6 ± 5.9	93.2 ± 8.0	64.9 ± 27.9	73.8 ± 21.8	23.0 ± 8.5	8.1 ± 5.2	5.55***	34.0
1.5—3.0	96.2 ± 8.9	83.6 ± 19.5	96.1 ± 2.4	63.4 ± 27.5	66.5 ± 26.0	41.0 ± 12.2	21.1 ± 10.2	2.47*	38.0
3.0—4.5	88.9 ± 14.9	68.5 ± 24.9	96.8 ± 1.5	61.8 ± 24.1	60.2 ± 23.6	38.9 ± 8.0	16.8 ± 9.7	2.22*	39.0
4.5—6.0	84.5 ± 21.1	58.6 ± 25.1	96.7 ± 1.3	50.9 ± 19.9	60.8 ± 21.8	37.8 ± 11.1	17.5 ± 10.2	2.56*	39.0
F	3.23*	13.41***	3.13*	1.29	1.47	13.26***	7.32***		
HSD 5 %	12.1	16.9	3.5	20.8	19.1	8.3	7.5		

frozen soil, where the decomposition can continue more effectively than in the southern spruce stands which normally get a ground frost. In the fall of 1969 the snow in Kuusamo fell on nearly thawed soil, and the ground frost practically did not develop at all. At Utsjoki the melting of snow is so slow that the decomposition in the spring is very limited before mid-June. Similarly, the ground freezes in the fall more regularly. The effect on decomposition rate of different timber crops and soils is clearly seen, especially at the plots of Juupajoki and Utsjoki.

3.2. *Rate of decomposition during the year*

The rate of decomposition on the southernmost experimental plots (Aarhus, Lund and Juupajoki) was so great that the decomposition percentage was 90—100 (Table 3). This implies that the results are not quite usable. In reality the decomposition could have been, compared to smaller percentage, even more intensive and the differences consequently larger. The value of the method is rapidly decreased if the decomposition exceeds 80 %. A comparison between the uppermost layers at Aarhus and Lund can therefore be only indicative. The same is also true for the pine stand at Juupajoki. The method is at its best when the decomposition rate is 30—60 %. In favorable conditions the pieces of cellulose may be decomposed to over 90 % in only 4 months (GOLLEY 1960). Such a complete decomposition in Finnish conditions requires a much longer time even at the most fertile sites (LÄHDE 1966).

In any case the decomposition rate is most rapid during the whole year in the pine stand of Juupajoki, and in the surface layer at the hardwood stands of Aarhus and Lund it is about of the same magnitude. At the experimental plot of Lund in the deepest layer (4.5—6.0 cm) the rate is of the same order of magnitude as in the spruce stand of Juupajoki and the thick humus layer of the spruce stand at Kuusamo.

It is of interest that in the birch mixed spruce stand of Kuusamo the rate is even faster than in the spruce stand of Juupajoki. This is probably due to the amount of shade in the latter stand and the mixture of the

Table 4. Weight loss (percent of dry weight) during the summer (ca. 1970-06-10. . .1970-09-10) of cellulose in various depths of the soil. Calculations are based on the results in Tables 2 and 3.

	Location and stand						
Depth cm	Aarhus Beech	Lund Oak-hazel	Juupajoki Pine	Juupajoki Spruce	Kuusamo Spruce-birch	Utsjoki Birch	Utsjoki Pine
0—1.5	(24.4)	(24.2)	(4.2)	19.1	42.1	26.5	18.0
1.5—3.0	(29.0)	23.7	(6.3)	20.5	33.7	26.9	14.6
3.0—4.5	23.5	20.5	(9.3)	24.3	24.2	26.1	17.1
4.5—6.0	27.2	17.3	(19.8)	27.8	24.9		

birch *(Betula pubescens)* in the open stand at Kuusamo.

Between the spruce experimental plots (Juupajoki and Kuusamo) there are no statistically significant differences, although the average speed of decomposition decreases with increasing soil depth. On the plots south of Juupajoki and Kuusamo the differences are significant. On the plots north of Juupajoki and Kuusamo (Utsjoki) the differences between depths are such that the decomposition in the surface (0—1.5 cm) layer is somewhat slower than in the deeper layers. The reason may lie in the frost upheaval of the cellulose dags.

3.3. Rate of decomposition during the summer

The rate of decomposition during the summer (ca. June 15—Sept. 15) may be calculated by subtracting the amount of decomposition from fall to winter from the annual total (Table 4). The results are of no value when the percentage of decomposition approaches or exceeds 90 %. Thus the results from the plots of Aarhus and Juupajoki (pine) and the surface layers of the plot in Lund will not be examined. In table 4 the results from these plots are enclosed in parentheses.

There does not appear to be any difference between the deeper layers of the spruce stand in Juupajoki and the oak-hazel stand of Lund. Of particular interest is the fact that rate of decomposition is much faster during the summer at Kuusamo than on the other plots. Also, in the birch stand at Utsjoki the rate is as fast as on the other plots, except the one at Kuusamo, during the summer. In the pine stand of Utsjoki the rate is somewhat slower than on the others, but the difference is not as marked as during the other seasons. The summer of 1970 was clearly warmer than the average. The high humidity of the climate in Lapland results in sufficient moisture, even during the summer, for the decomposition process. This is also true for Kuusamo.

4. Conclusions

In this study an attempt has been made to elucidate, by means of the so-called cellulose method, how the decomposition activity of the soil differs in various forest stands in different parts of the Nordic countries.

Based on the results it may be concluded that the geographical location, the timber crop of the stand and the soil quality have a marked influence on the decomposition activity of the soil. From south to north the rate of decomposition decreases significantly. The decrease is greatest moving from southern and central Finland to the very north of the country (Utsjoki). Thus, e.g. the rate of decomposition of cellulose during the year in a pine stand of Utsjoki is at the most 1/6 that of a comparable pine stand in southern Finland.

In a birch stand in Utsjoki, compared to a pine stand, the decomposition is 2—3 times faster. In a pine stand in Juupajoki the decomposition is twice as fast as in a spruce stand at the same location. Even a small amount of birch mixed into a spruce stand appears to increase the rate of decomposition as compared to a pure spruce stand.

The rate of decomposition appears to be more rapid in the spring and early summer; but also, in the winter decomposition occurs under the snow cover.

The decomposition decreases with the depth of the soil layer. The differences within a 6 cm surface layer of the soil are not, however, very great.

On the basis of the results of this study some conclusions can be made, e.g. about how fast waste paper left on the ground may decompose in different geographical conditions and forest stands. Also, the results indicate to what extent the local conditions have to be considered when using different types of forest seedling containers. It is obvious that careful and cautious one must be in dealing the farther north we are operating, the more with these phenomena.

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